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Chapter 10. Precipitation Enhancement

Precipitation enhancement, commonly called "cloud seeding," artificially stimulates clouds to produce more rainfall or snowfall than they would naturally. Cloud seeding injects special substances into the clouds that enable snowflakes and raindrops to form more easily. Precipitation enhancement is the one form of weather modification done in California. Other forms include hail suppression (reducing the formation of large, damaging hailstones) and fog dispersal (when fog is below freezing temperature) projects are conducted in other states. (There are some unconfirmed reports of hail suppression attempts in the San Joaquin Valley with hail cannons, but the scientific basis for this method is dubious).

Winter orographic cloud seeding has been practiced in California since the early 1950s. Most of the projects are along the central and southern Sierra Nevada with some in the Coast Ranges. The projects generally use silver iodide as the active seeding agent, supplemented by dry ice if aerial seeding is done. Silver iodide can be applied from ground generators or from airplanes. Occasionally other agents, such as liquid propane, have been used. In recent years, some projects have been trying hygroscopic materials (substances that take up water from the air) as supplemental seeding agents. Figure 10-1 shows rain and snow enhancement programs which had operated at some time during recent years. (Most are long term projects and were operated in all or most years. A few, such as Monterey County, only ran in one or two seasons.) Historically the number of operating projects has increased during droughts, up to 20 in 1991, but have leveled off at about a dozen in the more normal years. Most of the projects suspend operations during the very wet years once enough snow has accumulated to meet their water needs.

PLACEHOLDER Figure 10-1 Weather Modification Project Areas in 2011

Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

State requirements for sponsors of weather modification projects consist of filing a Notice of Intention (NOI) initially and every 5 years for continuing projects, some record keeping by operators and annual or biennial reports to DWR. The items to include in the NOI can be obtained from DWR. In addition, sponsors need to comply with the California Environmental Quality Act. Annual letter notices should also be sent to the Board of Supervisors of affected counties and to DWR. There are also activity reports to be sent to the National Oceanic and Atmospheric Administration which give the number of days and hours of operation and the amounts of seeding material applied.

Policy statements by both the American Meteorological Society in 1998 and the World Meteorological Organization in 2007support the effectiveness of winter orographic cloud seeding projects, although they cite the problem of the uncertainty in results. A more detailed treatment of weather modification capabilities, position statements, and the status of the discipline is in "Guidelines for Cloud Seeding to Augment Precipitation", 2nd Edition, ASCE Manuals and Reports on Engineering Practice No. 81, "Guidelines for Cloud Seeding to Augment Precipitation," published in 2006.

An encouraging development was an editorial in the international journal "Nature" in June, 2008, advocating a renewed push for scientific research into weather modification activities. For years, weather modification supporters faced a perceived negative bias in the scientific community. The editorial in a

widely respected scientific journal may mark a turn in opinion. Massive weather modification efforts in China for the 2008 Olympics did not go unnoticed in the press also that year. In 2011, evaluations of a 5 year experimental program in the Snowy Mountains of southeastern Australia confirmed a significant precipitation increase in seeded storms.

Cloud seeding has advantages over many other strategies of providing water. A project can be developed and implemented relatively quickly without multiyear lead times. In the snow zone, it could offset some of the loss in snowpack expected from global warming. This may be of benefit to mountain meadows and would delay the fire season in the forest. As one of the resource management strategies in Bulletin 160-09, precipitation enhancement would qualify as part of IWRM. Seeding opportunities tend to be greater in northern California than in the south because of more frequent storms and cooler temperatures.

Since 2009, there has not been many new developments in weather modification in California. Most of the projects have continued to operate as before. The demise of one of the oldest commercial operators in the field, Atmospherics Incorporated in Fresno, led to some changes as sponsors had to fill in with someone else. A new firm, RHS Consulting, Ltd entered the field and, in 2011, conducted operations on three of the southern Sierra watersheds—the San Joaquin, Kaweah, and Kern.

The Pacific Gas and Electric Company had planned new project on the Pit and McCloud Rivers in Northern California on the headwaters of Shasta Lake, but this has been dropped to avoid further controversies in light of the criticism of the firm in the San Bruno gas pipeline explosion in 2010. This would have been one of the more productive in California because of more frequent storms and being able to take advantage of natural storage by increasing precipitation recharge of the large volcanic aquifers which feed the Pit and McCloud Rivers year round and thereby increase hydroelectric power production. Potential yield could have been as much as 200,000 acre-feet. Much of the added precipitation would have gone into recharging the large volcanic aquifer which supplies the year round springs in the region.

Another area of interest to California is the Colorado River basin, where a lengthy drought has caused the seven states to look at all potential options. The best hope of augmenting Colorado River water supply is wintertime cloud seeding in the headwater states of Colorado, Utah, and Wyoming. There are already many seeding programs in place. However, the basin states have agreed to work together in a program for implementing new programs and to designate new areas for seeding and possibly longer seasons of operation for existing projects. There were 15 projects already operating in the upper Colorado River region; there may be a potential for up to 15 more in the basin, including 4 in Arizona. From a 2006 study by North American Weather Consultants, the combined potential yield of the new programs could be 800,000 AF per year on average. This is based on a 10 percent increase in precipitation. Additional amounts could be obtained by augmenting the existing programs, primarily by funding a longer season of operation. As a starter, the Lower Basin states added about $390,000 per year in the three years from 2010 through 2012 to enhance Upper Basin cloud seeding efforts.

It is obvious that much more research in weather modification is desirable. The kind needed and the equipment needed are beyond the ability and funding of independent project sponsors, although much can be gained from piggybacking research onto existing programs. To this end, legislation was introduced in the 110th Congress by Senator Kay Hutchison of Texas and Congressman Mark Udall of Colorado for weather modification research and to increase the effectiveness of existing programs through applied research. This federal research funding effort was unsuccessful.

In California, proposals have been made to the CEC's Public Interest Energy Research (PIER) program for additional research into cloud seeding to evaluate the effectiveness of existing programs in the State and optimize their effectiveness. Justification would be the potential impact on hydroelectric energy production. This approach would survey the latest scientific advances in cloud physics, remote sensing, atmospheric science, seeding technologies and evaluating strategies and recommend the best course of action to maximize the contribution of operational cloud seeding programs to the State's water and energy supplies. Some study could also be made on the potential effect of global warming and atmospheric pollution on seeding practices and capabilities. DWR recommends that PIER include and fund research on cloud seeding in their activities.

The State of Wyoming has undertaken a major weather modification research program which is now in its 7th year (2006-2012). The objective is to evaluate, with help from the scientists at the National Center for Atmospheric Research, the potential for increased snowpack in the Sierra Madre and Medicine Bow Mountains of southern Wyoming with a randomized experimental design. Some storms are seeded and some are left unseeded with extensive measurements of moisture tracking in the air and results on the ground. Another couple of years will be needed after the current one to gain the 120 to 150 cases needed to detect with statistical confidence a positive increase in snowpack due to seeding.

Progress in confirming snowfall enhancement has been made in the Snowy Mountains of Australia. A recent scientific paper by Manton and Warren shows an increase of 14 percent in precipitation when comparing seeded to unseeded experimental units from 2005 through 2009 during passage of winter cold fronts.

Benefits from Precipitation Enhancement

In California, all precipitation enhancement projects are intended to increase water supply or hydroelectric power. The amounts of water produced are difficult to determine, but estimates range from a 2 to 15 percent increase in annual precipitation or runoff. A National Research Council (NRC) 2003 report on weather modification had limited material on winter orographic cloud seeding, such as practiced in California and other western states. However, the report did seem to concur that there is considerable evidence that winter orographic weather modification does work, possibly up to a 10 percent increase. A 2012 study by the Utah Department of Natural Resources (updating a 2005 study through the 2010 season) showed an average increase in April 1 snowpack water content ranging from 3 to 15 percent from a group of projects which had been operating from 7 (High Uintas) to 32 (Central/Southern Utah) years. The overall estimated annual runoff increase for the State was about 180,000 acre-feet, or about 6 percent for the study area. Estimated costs in 2010 were $2.27 per acre-foot from these ground seeding programs.

Actual increases in annual runoff are probably less in California than in Utah. A new estimate made for this bulletin by DWR staff is that the combined California precipitation enhancement projects, on

average, generate about 400,000 acre-feet annually, which would be an average of about a 4 percent increase in runoff.

Accepting the P. G & E estimate for the formerly proposed Pit River cloud seeding project of 200,000 acre-feet for that region (which is one of the most favorable areas for cloud seeding because of more frequent storms and generally colder weather conditions), another 200,000 to 300,000 acre-feet per year may be available in other areas. Thus, a reasonable State total could average another 400,000 acre-feet per year. Many of the other best prospects are in the Sacramento River basin, in watersheds that are not seeded now. The Lahontan regions are already well covered by cloud seeding projects, except for the Susan River and the Carson River. With the exception of the upper Trinity River watershed, and perhaps the Russian River, there is little new potential in the North Coast region because not much extra rainfall could be captured due to limited storage capacity. There is also potential to increase water production by more effective seeding operations in existing projects. Precipitation enhancement should not be viewed as a remedy for drought. Cloud seeding opportunities are generally fewer in dry years. It works better in combination with surface or groundwater storage to increase average supplies. In the very wet years, when sponsors already have enough water, cloud seeding operations are usually suspended.

Potential Costs

Costs for cloud seeding generally would be less than $30 per acre-foot per year. State law says that water gained from cloud seeding is treated the same as natural supply in regard to water rights. Southern California projects would be more expensive because of fewer seeding opportunities, but imported supplies are also more expensive there.

It is estimated that about $3 to 5 million is being spent now on yearly operations. Realizing the additional 300,000 to 400,000 acre-feet of potential new supply could require an initial investment of around $8 million for planning, reports, and initial equipment, plus around $6 million in annual operations costs. Over the next 25 years, that would add up to about $150 million, which would be nearly $ 22 per acre-foot.

(Note--This cost estimate is preliminary and may be adjusted in the next revision)

PLACEHOLDER Figure 10-2 Ground-Base Seeder

Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

Picture above courtesy of Pacific Gas and Electric Company

Major Issues for Precipitation Enhancement

Reliable Data

No complete and rigorous comprehensive study has been made of all California precipitation enhancement projects. Part of the reason is the natural variability of weather, and the difficulty in locating unaffected control basins. Some studies of individual projects have been made in the past years on certain projects, such as the Kings River, which have shown increases in water. A recent attempt by Dr. Bernard Silverman, published in the 2010 Journal of Atmospheric Research, published by Elsevier in September,

2010 represents the best efforts so far on the longer running cloud seeding projects and is generally positive in showing results. Aerial seeding, or combination aerial and ground seeding, showed better results than ground seeding alone.

Operational Precision

It is difficult to target seeding materials to the right place in the clouds at the right time. There is an incomplete understanding of how effective operators are in their targeting practices. Chemical tracer experiments have provided support for targeting practices. New seeding agents, transport and diffusion studies with some of the new atmospheric measuring tools like some currently being employed by the NOAA hydrometeorological test bed experiments would be helpful.

Concern over Potential Impacts

Questions about potential unintended impacts from precipitation enhancement have been raised and addressed over the years. Common concerns relate to downwind effects (enhancing precipitation in one area at the expense of those downwind), long term toxic effects of sliver, and added snow removal costs in mountain counties. The U.S. Bureau of Reclamation did extensive studies on these issues. The finding are reported in its Project Skywater programmatic environmental statement in 1977 and its Sierra Cooperative Pilot Project EIS in 1981. The available evidence does not show that seeding clouds with silver iodide causes a decrease in downwind precipitation; in fact, at times some of the increase of the target area may extend up to 100 miles downwind (Ref. 1981 SCPP EIS). (Note: the author of this section attended a new seminar specifically on downwind effects at the end of April, 2012 in Las Vegas at the annual meeting of the Weather Modification Association in which the earlier findings of no loss to downwind areas was confirmed; often adjacent downwind areas also showed some increase.)

The potential for eventual toxic effects of silver has not been shown to be a problem. Silver and silver compounds have a rather low order of toxicity. According to the Bureau of Reclamation, the small amounts used in cloud seeding do not compare to industry emissions of 100 times as much into the atmosphere in many parts of the country or individual exposure from tooth fillings. Watershed concentrations would be extremely low because only small amounts of seeding agent are used. Accumulations in the soil, vegetation and surface runoff have not been large enough to measure above natural background. A 2004 study done for Snowy Hydro Limited in Australia has confirmed the earlier findings cited above. Some silver accumulation testing by PG & E on the Mokelumne River and Lake Almanor watersheds was reported on at the 2007 annual meeting of the Weather Modification Association. Both watersheds have been seeded for more than 50 years. Sampling at Upper Blue Lake and Salt Springs Reservoir showed very low to non-detectible concentrations in water and sediment. Similar results were found at Lake Almanor in testing water, sediment and fish samples during the 2000 to 2003 period. Amounts were far below any toxic levels and there was little to suggest bio-accumulation. Therefore, continued operations should not result in any significant chronic effect on sensitive aquatic organisms.

In regard to snow removal, little direct relationship to increased costs was found for small incremental changes in storm size because the amount of equipment and manpower to maintain the roadway is essentially unchanged. That is, the effort is practically the same to clear a road of 5.5 inches compared to 5 inches.

All operating projects have suspension criteria designed to stop cloud seeding any time there is flood threat. Moreover, the type of storms that produce large floods are naturally quite efficient in processing moisture into rain anyway. In such conditions, seeding is unlikely to make a difference.

Funding

Little federal research funding for weather modification has been available in the past 20 years. The Bureau of Reclamation had some funding in 2002 and 2003 in the Weather Damage Mitigation program. Desert Research Institute of Nevada did obtain a grant of $318,000 from this source early in 2003 to evaluate its seeding in the eastern Sierra.

The Bureau of Reclamation is also providing some funds to Desert Research Institute for its current Walker River program to augment stream inflow to Walker Lake in Nevada

Attempts were made with bills introduced in the 110th Congress which would reestablish federal support for more weather modification research, some which would have provided research support on existing operating projects. This legislation is supported by the Western States Water Council, the seven Colorado River Basin states, the Colorado River Board of California and others. These bills, S.1807 (Hutchinson) and H.R. 3445 (Udall) did not pass.

The major research effort in recent years has been State funded by Wyoming in an extensive test of cloud seeding in two adjacent mountain regions, the Sierra Madre and Medicine Bow Mountains. This is a classical randomized statistical experiment where some storms are seeded and some are not. About 30 cases will occur in an average winter season. So far, at the end of 2012 the project has produced 123 cases, but needs about 60 more to raise statistical confidence according to NCAR researchers—which would be at least 2 more seasons. The Wyoming Legislature in 2012 provided two more years of funding to complete the experiment. Costs are on the order of $1,000,000 per year.

Inadvertent Weather Modification

There is evidence that human activities such as biomass burning, transportation, and agricultural and industrial activities modify local and sometimes regional weather. The effects of aerosols on clouds and precipitation are complex. Recent studies by Ramanathan and Rosenfeld suggest suppressed precipitation formation in affected clouds due to pollution and dust. Some aerosols can enhance precipitation and some, especially the very fine aerosols in diesel smoke, can reduce precipitation. Much more research is needed to evaluate the air pollution effects on precipitation processes and the amount of impact as well as possible effects on cloud seeding programs. It is possible that some of the California cloud seeding projects have offset a potential loss in precipitation from air pollution, which may have obscured a more positive signal from the weather modification projects. Research work in Israel has demonstrated such effects.

Recent research by Scripps and the Pacific Northwest Lab has indicated that dust from western China can increase Northern Sierra west slope precipitation.

Recommendations to Increase Precipitation Enhancement

1. The State should support the continuation of current projects as well as the development of new projects and help in seeking research funds for both old and new projects. Operational funding support for new projects may be available in the IWRM program.
2. DWR should collect base data and project sponsor evaluations of existing California and other western states precipitation enhancement projects, independently analyze them, and perform research on the effectiveness of this technology to supplement water supplies while minimizing negative impacts.
3. DWR should support efforts to investigate the potential to augment Colorado River supply by cloud seeding, in cooperation with the Colorado River Board, the other Colorado River Basin Sates, the U.S. Bureau of Reclamation, and Metropolitan Water District of Southern California.
4. DWR, in partnership with the Bureau of Reclamation, and seeking cooperation with P. G. & E, should produce an EIR/EIS on a Pit River project similar to the one proposed several years ago, since this is an area with one of the best potential yields which could benefit both the CVP and SWP (who share in-basin use above and in the Delta) and there would appear to be multiple State benefits from augmenting recharge of the huge northeastern California volcanic aquifer.
5. DWR should support research on cloud physics and cloud modeling being done by the National Oceanic and Atmospheric Administration labs and academic institutions. With improvement, these models may become tools to further verify and test the effectiveness of cloud seeding activities.
6. The State should support research on potential new seeding agents, particularly ones which would work at higher temperatures. Global warming may limit the effectiveness of silver iodide, the most commonly used agent, which requires cloud temperatures well below freezing, around -5^{o} C, to be effective. The increasing costs of silver is a detriment to some ongoing projects.
7. DWR should support efforts by California weather modification project sponsors, such as that proposed in 2002-03 by Santa Barbara County Water Agency, to obtain federal and State research funds for local research experiments built upon their operating cloud seeding projects. In this regard, DWR recommends that the CEC PIER program include research studies on weather modification.

Precipitation Enhancement in the Water Plan

[This is a new heading for Update 2013. If necessary, this section will discuss the ways the resource management strategy is treated in this chapter, in the regional reports and in the sustainability indicators. If the three mentions are not consistent, the reason for the conflict will be discussed (i.e., the regional reports are emphasizing a different aspect of the strategy). If the three mentions are consistent with each other (or if the strategy isn't discussed in the rest of Update 2013), there is no need for this section to appear.]

References

ASCE Manual No. 81 "Guidelines for Cloud Seeding to Augment Precipitation" Second Edition, 2006.

ASCE Policy Statement No. 275, "Atmospheric Water Resources Management", 2003.

ASCE/EWRI 42-04 “Standard Practice for the Design and Operation of Precipitation Enhancement Projects”, 2004.

National Oceanic and Atmospheric Administration

Desert Research Institute, Reno, Nevada

American Meteorological Society

World Meteorological Organization

USBR Project Skywater Publications, various, 1975-1987, including those of the Sierra Cooperative Pilot Project in California.

Sierra Cooperative Pilot Project, Environmental Assessment and Finding of No Significant Impact, USBR, Denver, 1981.

USBR Lahontan Basin Area Office, Environmental Assessment for the Walker River Basin Cloud Seeding Project, December 2010. Also, Finding of No Significant Impact, Walker River Basin Cloud Seeding Project, December 2010.

Cardno ENTRIX, Geochemistry and Impacts of Silver Iodide Use in Cloud Seeding, May 2011, prepared for P. G. & E. Cardno ENTRIX, Concord, CA.

A. Givati and D. Rosenfeld, “Quantifying Precipitation Suppression Due to Air Pollution”. 2004, Journal of Applied Meteorology Vol 43, pp 1038-1056.

Byron Marler, “Cloud Seeding Impacts? Water, Sediment and Tissue Studies”, Presentation at the annual meeting of the Weather Modification Association, at San Francisco, 2007.

Michael J. Manton, Loradena Warren, Suzanne Kenyon, Andrew Peace, Shane Bilish and Karen Kemsley, “A Confirmatory Snowfall Enhancement Project in the Snowy Mountains of Australia. Part I: Project Design and Response Variables, 2011, Journal of Applied Meteorology, Vol 50, pp 1432-1447.

Michael J.Manton and Loradena Warren, “A Confirmatory Snowfall Enhancement Project in the Snowy Mountains of Australia. Part II: Primary and Associated Analyses, 2011, Journal of Applied Meteorology and Climatology, Vol 50, pp 1448-1458.

Nature editorial “Change in the Weather” on the need for weather modification research, Vol 453, p 957-958, June 19, 2008.

NRC report “Critical Issues in Weather Modification Research”, The National Academies Press, Washington, DC, 2003.

V. Ramanathan, P.J. Crutzen, J. T. Kiehl and D. Rosenfeld, "Aerosols, Climate, and the Hydrologic Cycle", 2001, Science magazine, Dec, 7, 2001. www-ramanathan.ucsd.edu.

V. Ramanathan and M. V. Ramana, "Atmospheric Brown Clouds, Long Range Transport and Climate Impacts", EM, Dec. 2003, pp 28-33. www-c4.ucsd.edu.

UNEP and Center for Clouds, Chemistry and Climate, 2002, "The Asian Brown Cloud: Climate and Other Environmental Impacts", UNEP, Nairobi.

The Weather Modification Association's Response to the NRC Report "Critical Issues in Weather Modification Research", report of a review panel, pp 53-82, Journal of Weather Modification, April, 2004.

North American Interstate Weather Modification Council Response to the NRC Report, April 2004, 2 pp on www.naiwmc.org.

Snowy Hydro Limited, Cooma, NSW, Australia, "Assessment of the Environmental Toxicity of Silver Iodide and Indium Iodide", by Dr. Brian Williams, Adelaide University, 2004.

T. Ryan, 2005: Weather Modification for Precipitation Augmentation and its Potential Usefulness to the Colorado River Basin States, Metropolitan Water District of Southern California, 34 p.

Bernard Silverman, 2010: An Evaluation of Eleven Operational Cloud Seeding Programs in the Watersheds of the Sierra Nevada Mountains, Journal of Atmospheric Research, Vol 27, No 4, published by Elsevier, Sept 2010.

Desert Research Institute, 2011: Cloud Seeding Project for Tahoe and Truckee Basins for WY2011, DRI, Oct 2011.

Desert Research Institute, 2011: Cloud Seeding Operations and Research in the Walker River Basin to Increase Water Delivery to Walker Lake, October 2010—March 2011 and April—Sept, 2011, DRI, October 2011.

D. Griffith, Mark Solak, Robert Almy and Dennis Gibbs, 2005: The Santa Barbara Cloud Seeding Project in Coastal Southern California, Operations and Research Spanning More than 50 Years, Annual Weather Modification Journal, 2005, WMA.

D. Griffith and M. Solak, 2006: The Potential use of Winter Cloud Seeding Programs to Augment the Flow of the Colorado River, proposed for the Upper Colorado River Commission, North American Weather Consultants, Sandy, UT, 49 p.

Kings River Conservation District, et al: Summary and Evaluation of 2010-2011 Winter Cloud Seeding Operations for the Kings River Watershed, CA. June 2011.

S. A. Hunter, 2007: Optimizing Cloud Seeding for Water and Energy in California, prepared for the California Energy Commission PIER Program, U.S. Bureau of Reclamation, Denver, CO, 38 p

Utah Division of Water Resources, 2005: “Utah Cloud Seeding Program, Increased Runoff/Cost Analysis, Salt Lake City, UT, 15 p. Utah Division of Water Resources, 2012: Utah Cloud Seeding Program, Increased Runoff/Cost Analyses, Salt Lake City, UT 19 p.

Workshop on Cloud Seeding, 2007, hosted by NSW Department of Environment and Conservation and Sydney Catchment Authority; Workshop Summary, 5 p.

Southwest Hydrology Magazine, March/April, 2007. Entire issue on Cloud Seeding. University of Arizona, Tucson, AZ, 44 p.

Figure 10-2 Weather Modification Project Areas in 2011

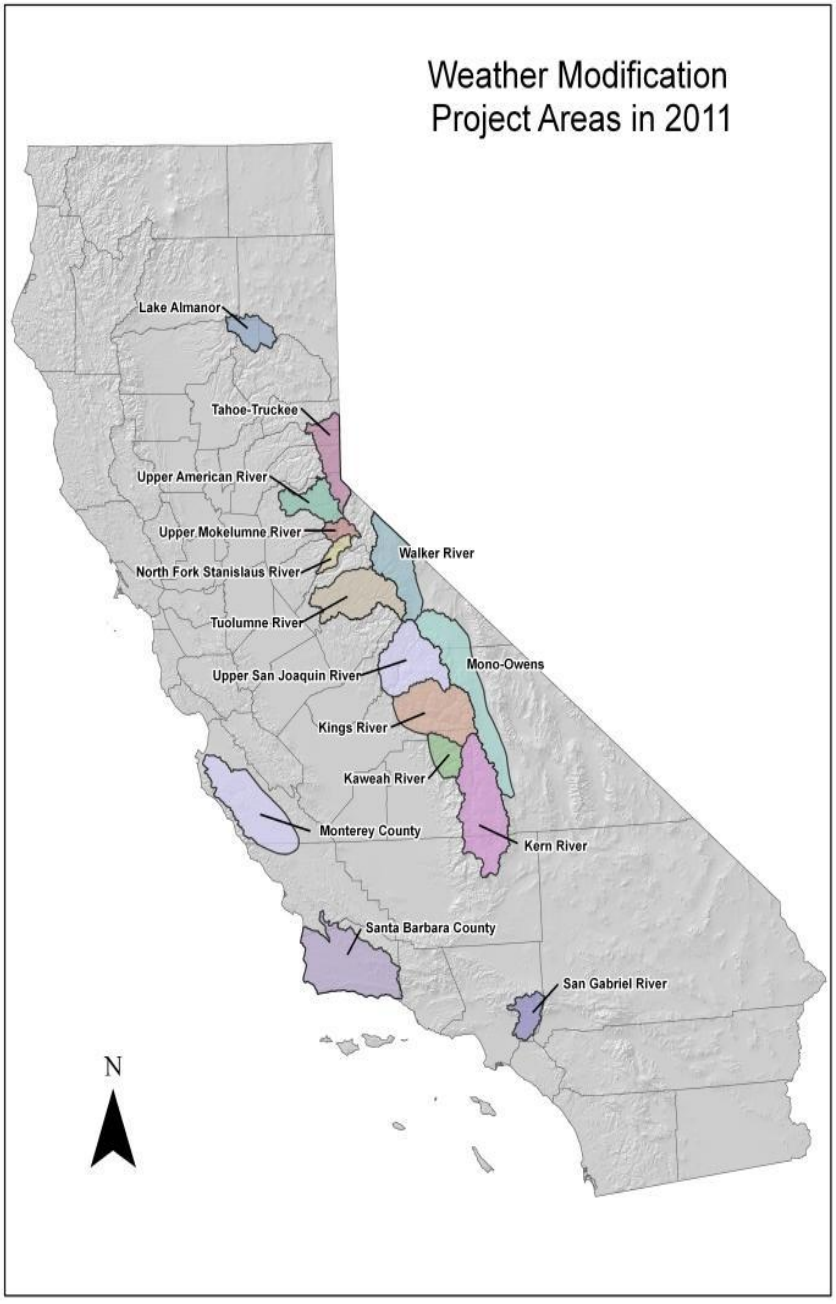

Figure 10-2 Ground-Based Seeder

Ground-Based Seeder